



# Cost Estimation @ the Speed of Light – Concurrent Engineering Modernization

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**Jet Propulsion Laboratory**  
California Institute of Technology

# Presentation Outline

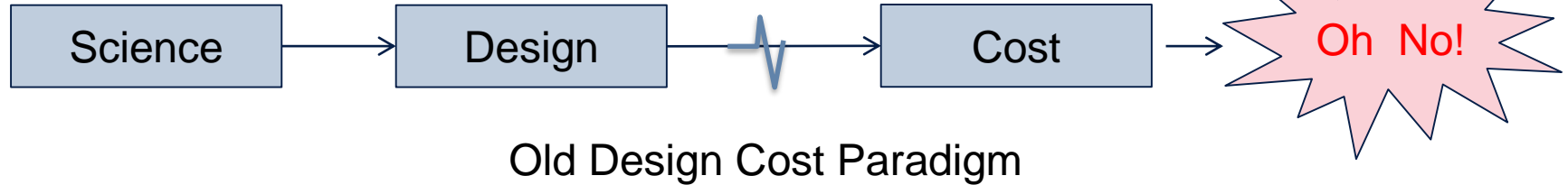
- Background/Overview
- Integrated Model Approach
- Cost Models
- Database
- “Take-Aways”

# Background/Overview

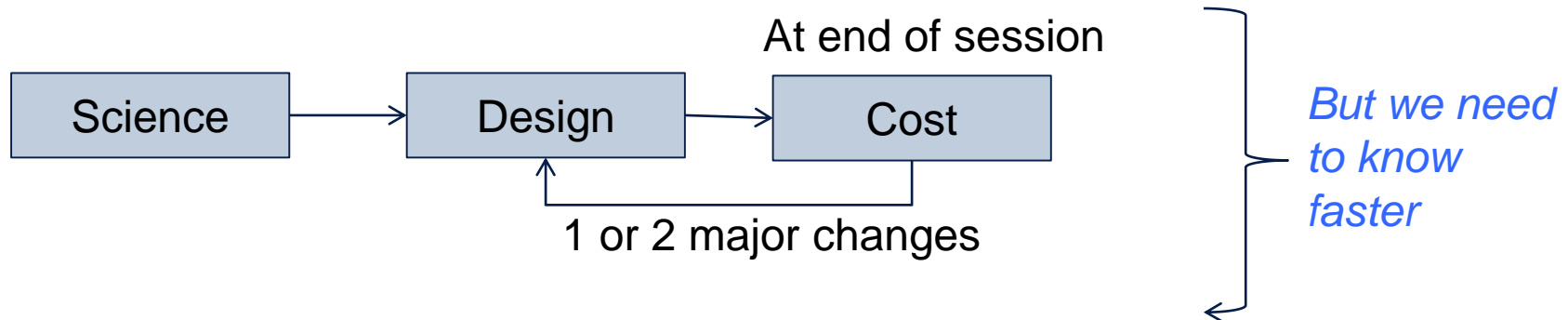
- Each year JPL submits 50 or more proposals and conducts hundreds of studies many in our Concurrent Engineering (CE) environment
- Over the decades, each organization has evolved their own data sets and costing methods most of which are ‘stovepiped’ snapshots of our past missions
- Two years ago a major process improvement project was started to improve how we cost in the CE teams and during the early formulation part of the lifecycle
- So this is our story

# The Problem

Too Much Time Passes



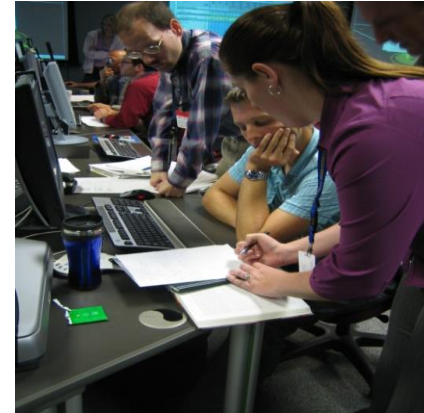
Team X Design Cost Paradigm Greatly Reduces Turn Around



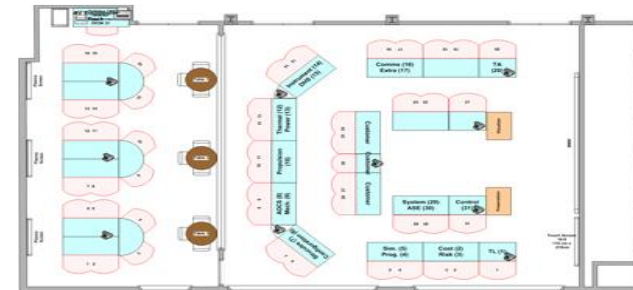
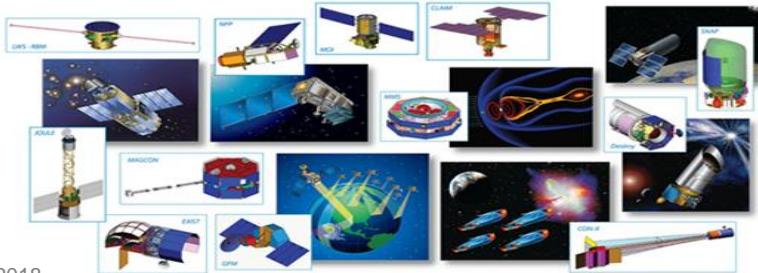
# What is Concurrent Engineering?

- Concurrent Engineering is a systematic approach by diverse specialists collaborating simultaneously in a shared environment, real or virtual, to yield an integrated design
- This approach is intended to cause the developers from the very outset to consider
  - All elements of the product life cycle, from conception to disposal, including cost, schedule, quality and user requirements

Data Shown is notional

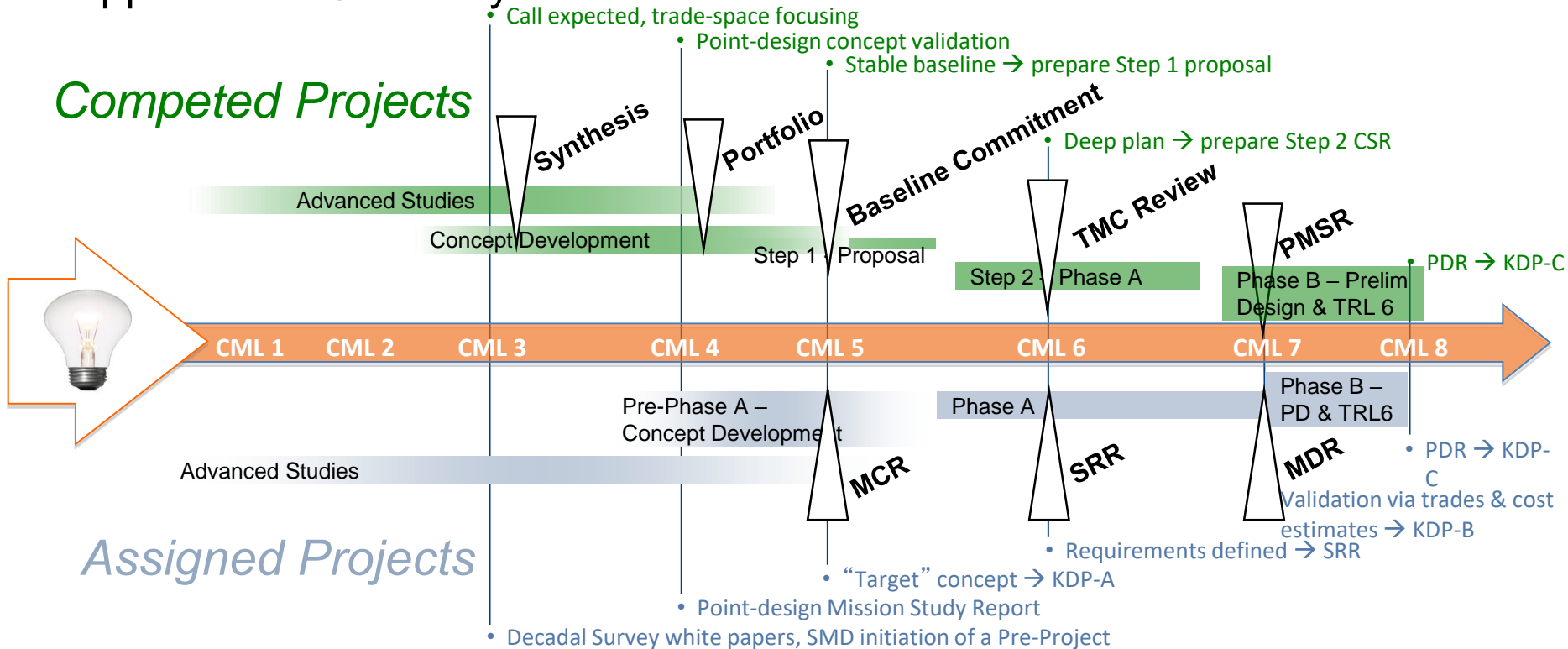


- [illegible]



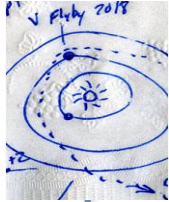
# Concept Maturity Levels (CMLs) - 2

## Mapped to NASA Lifecycle

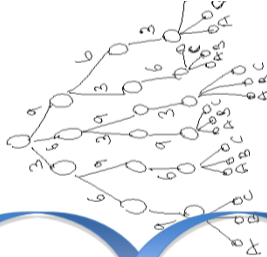


# Concept Maturity Levels - 3

Cocktail Napkin



Trade Space



Baseline Concept



Preliminary  
Implementation  
Baseline



CML 1

CML 2

CML 3

CML 4

CML 5

CML 6

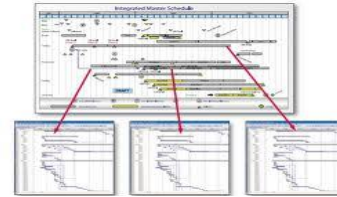
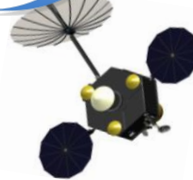
CML 7

CML 8

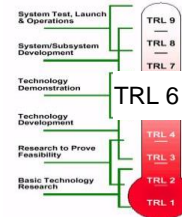
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Initial Feasibility

Point Design



Integrated Concept

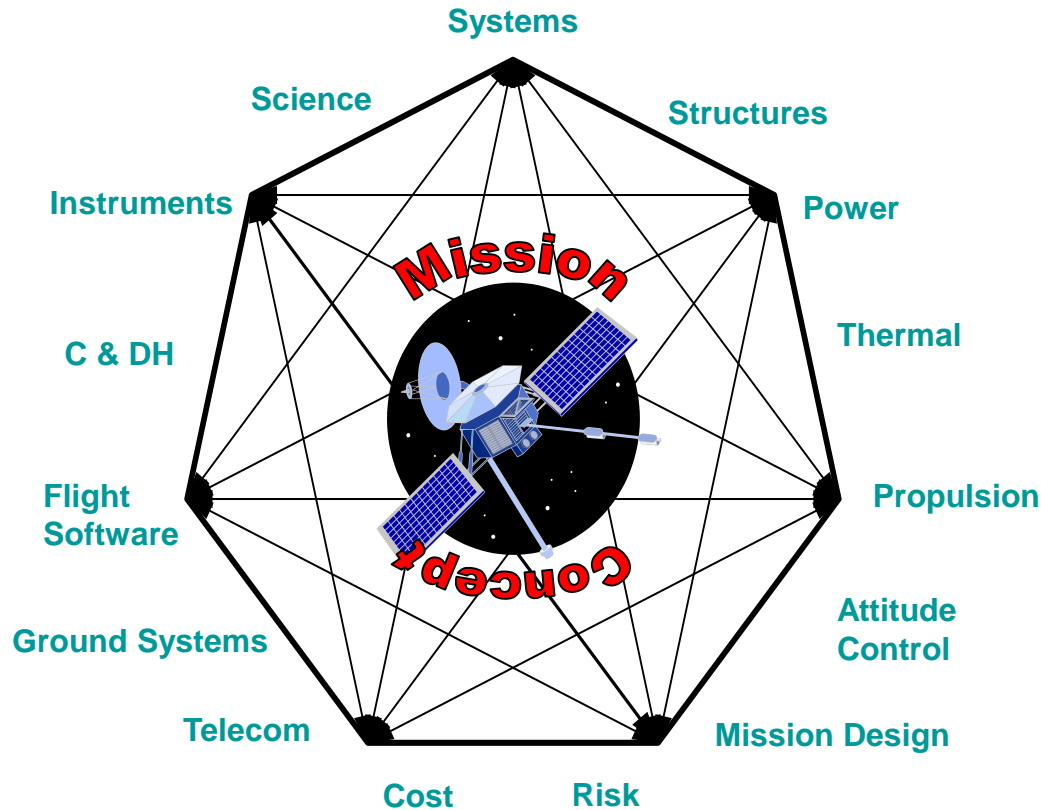


Integrated  
Baseline

Concurrent  
Engineering has  
demonstrated a  
major role here

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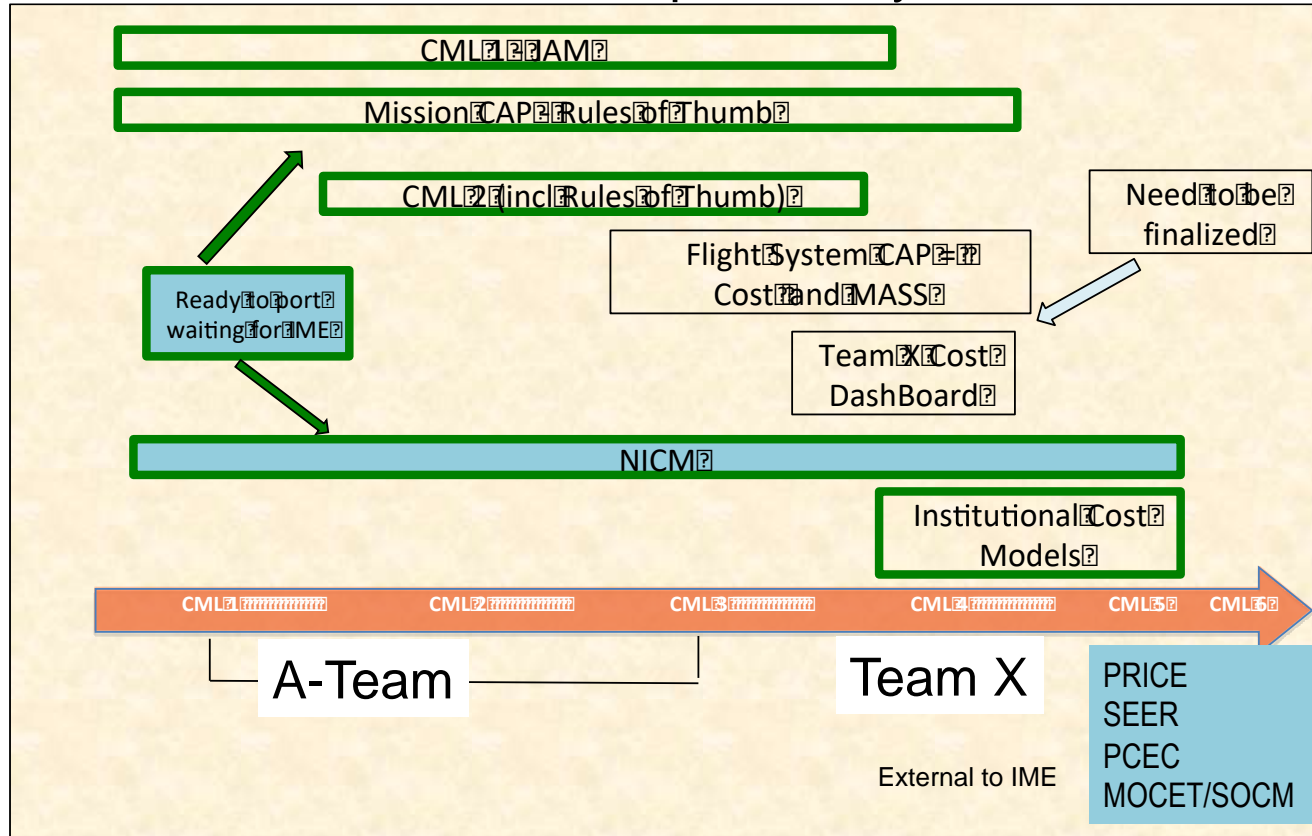
# Integrated Model Approach



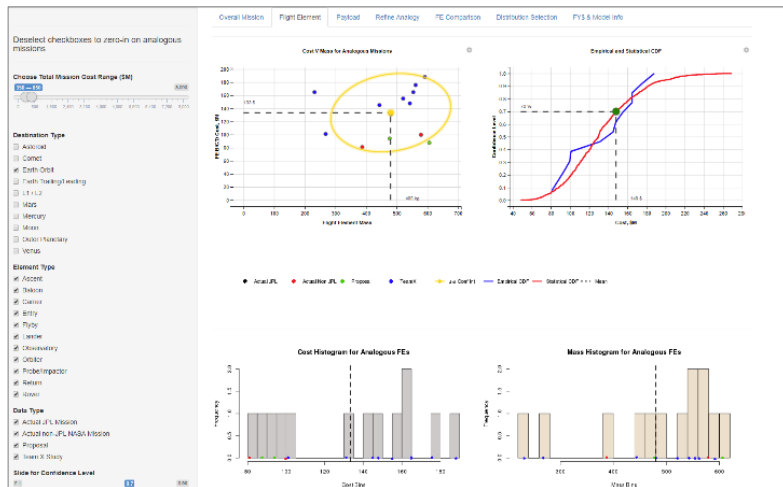
- Team X completes high level designs in 3 mornings or less
- We have always generated cost estimates during the sessions so design and cost can be traded off
- In the future we want to estimate cost in 'real time'

# Cost Models

## Different Cost Models for each Concept Maturity Level



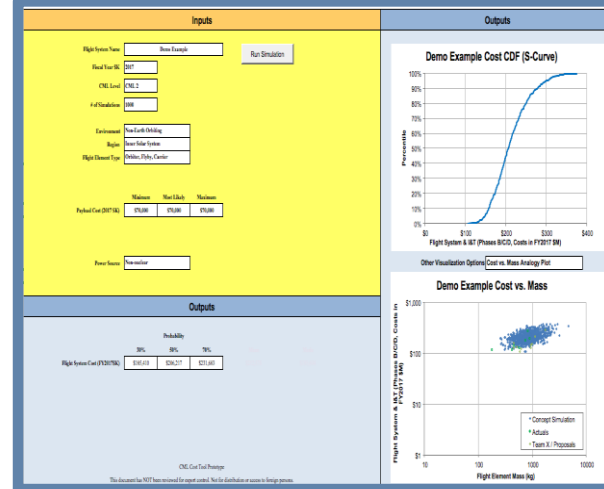
# Cost Models



CML1

Data Shown is notional

Proposal Mission Rules of Thumb Cost Estimator - Output						
WBS Element	Phases A thru D			Phases E thru F		
	\$M Phases A-D	% A-D Reserves	A-D Total With Reserves	Phases E-F	E-F Reserves	\$M With Reserves
PM, SE, MA	\$50.2	35%	\$67.8	\$0.0	15%	\$0.0
4 Science	\$10.6	35%	\$14.4	\$0.0	15%	\$0.0
5 Payload	\$76.0	35%	\$102.6			
6 Spacecraft	\$231.1	35%	\$312.0			
MOS/GDS	\$26.2	35%	\$35.4	\$5.3	15%	\$6.1
ATLO	\$0.0	35%	\$0.0			
11 E&PO	\$0.0	35%	\$0.0	\$0.0	15%	\$0.0
NAV & Miss Des	\$11.7	35%	\$15.8			
<b>Total</b>	<b>\$405.0</b>	<b>35%</b>	<b>\$547.9</b>	<b>\$5.3</b>	<b>15%</b>	<b>\$6.1</b>
8 Launch Vehicle	\$28.0	0%	\$28.0			
<b>TOTAL w/ RPS LAUNCH Activities, Per AO</b>			<b>\$575.9</b>			
Grand Total Life Cycle Cost (\$M)					<b>\$582.0</b>	

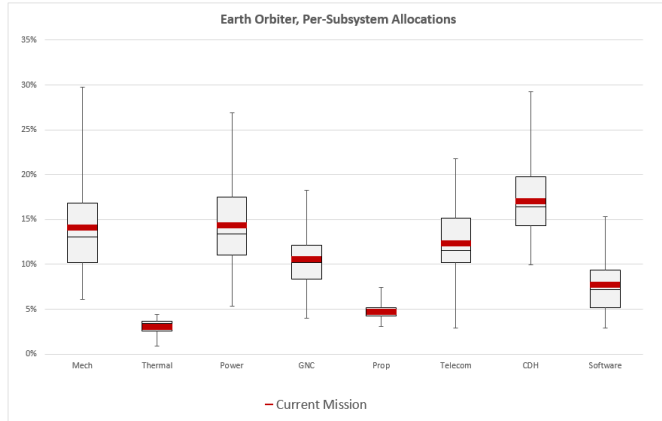


# Mission-Cost Allocation Percent Tools

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## EARTH ORBITERS

	Total Flight Element Cost (\$M)	Mech + Harness	Thermal	Power	GNC	Prop	Telecom	CDH	Software
Cost - Enter Total FE Cost Here	\$200	\$28	\$6	\$29	\$21	\$9	\$25	\$34	\$15
Calculated Percent Allocation	-	14.1%	3.0%	14.4%	10.6%	4.7%	12.3%	17.0%	7.7%

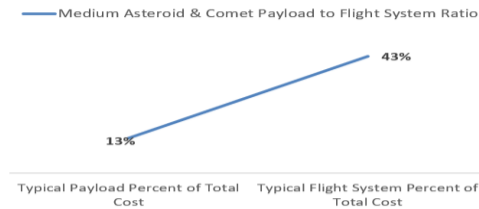


## Payload -> Flight System Cost Estimator

INPUTS	Mission Type	Asteroid & Comet
	Mission Size	Medium
	Payload Cost \$M FY16	\$ 95

OUTPUTS	Estimated FS Cost \$M FY16	\$ 317
	Estimated FS + PL Cost \$M FY16	\$ 412
	Mission Type	Asteroid & Comet
	Typical Payload Percent of Total Cost	13%
	Typical Flight System Percent of Total Cost	43%

## Medium Asteroid & Comet Payload to Flight System Ratio



## INPUTS: Phases A-D

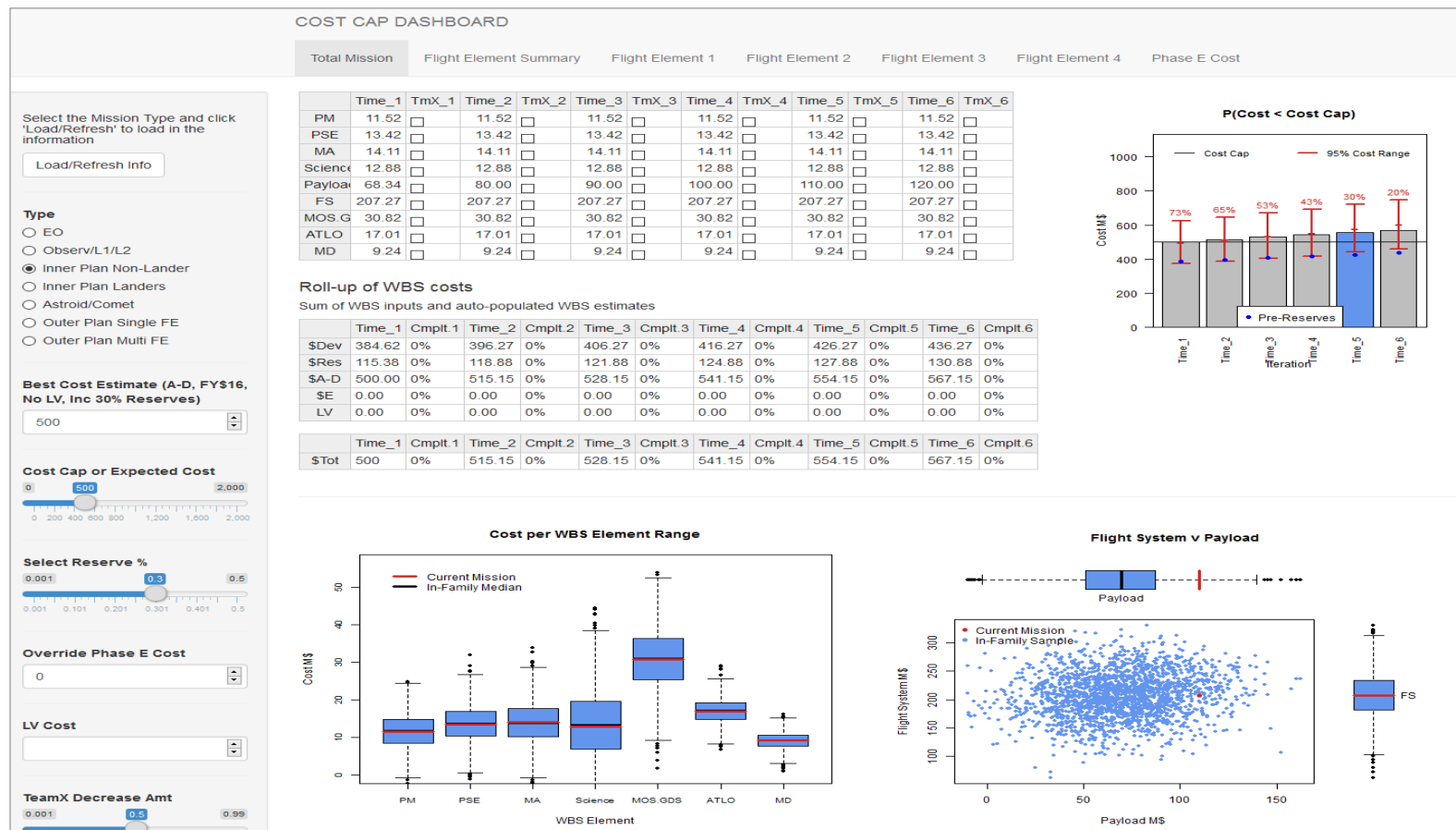
FS+PL cost \$M FY16	400
Total Mission Cost	
Mission Type	Asteroid & Comet
% Reserves	30%

## OUTPUTS: Phases A-D, \$M FY16

PM	16
PSE	17
MA	26
Science	19
Payload	94
FS	314
MOS/GDS	42
ATLO	24
Mission Design	14
Reserves	170
Total	735

# Team X Cost Dash Board

Data Shown is notional



# Mission & Cost Database (MCDB)

## Background

- Current Excel database hosts cost, schedule, and technical parameters (cost-drivers only) from JPL flown missions, Team X, Proposals, and other NASA center flown missions
- Originally built (~2009) for CER generation

## Current Activities

- Developing capability to populate database automatically from selected Team X studies
- Developing capability to populate database from templates for JPL historical actual data, proposal data, NICM, Software Cost Database, Cubesat cost data, and other data sources
- Providing a source of analogy data
- Enabling Rules of Thumb and CER generation capability directly from database
- Enabling data summarization and visualization

# Mission & Cost Database (MCDB)

## Benefits and Rationale

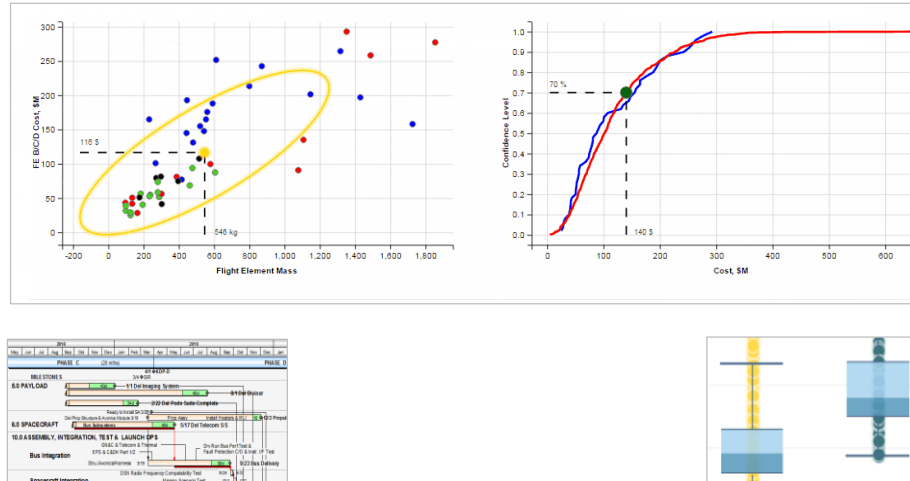
- Single source of “truth” for data
- Provide real-time data to Team X, A-team, proposers, and other formulation analysts so they can align estimates with historical information and previous proposals and studies
- Improve cost modeling efficiency and accuracy
- Provide decision-makers (e.g., ADMs/Section Managers) the data required to make sound recommendations

# Mission & Cost Database (MCDB)

Data Shown is notional

## Vision

Redefine cost engineering in formulation by facilitating credible and transparent cost estimation, schedule estimation, & risk identification early in a mission concept, enabling these parameters to influence design



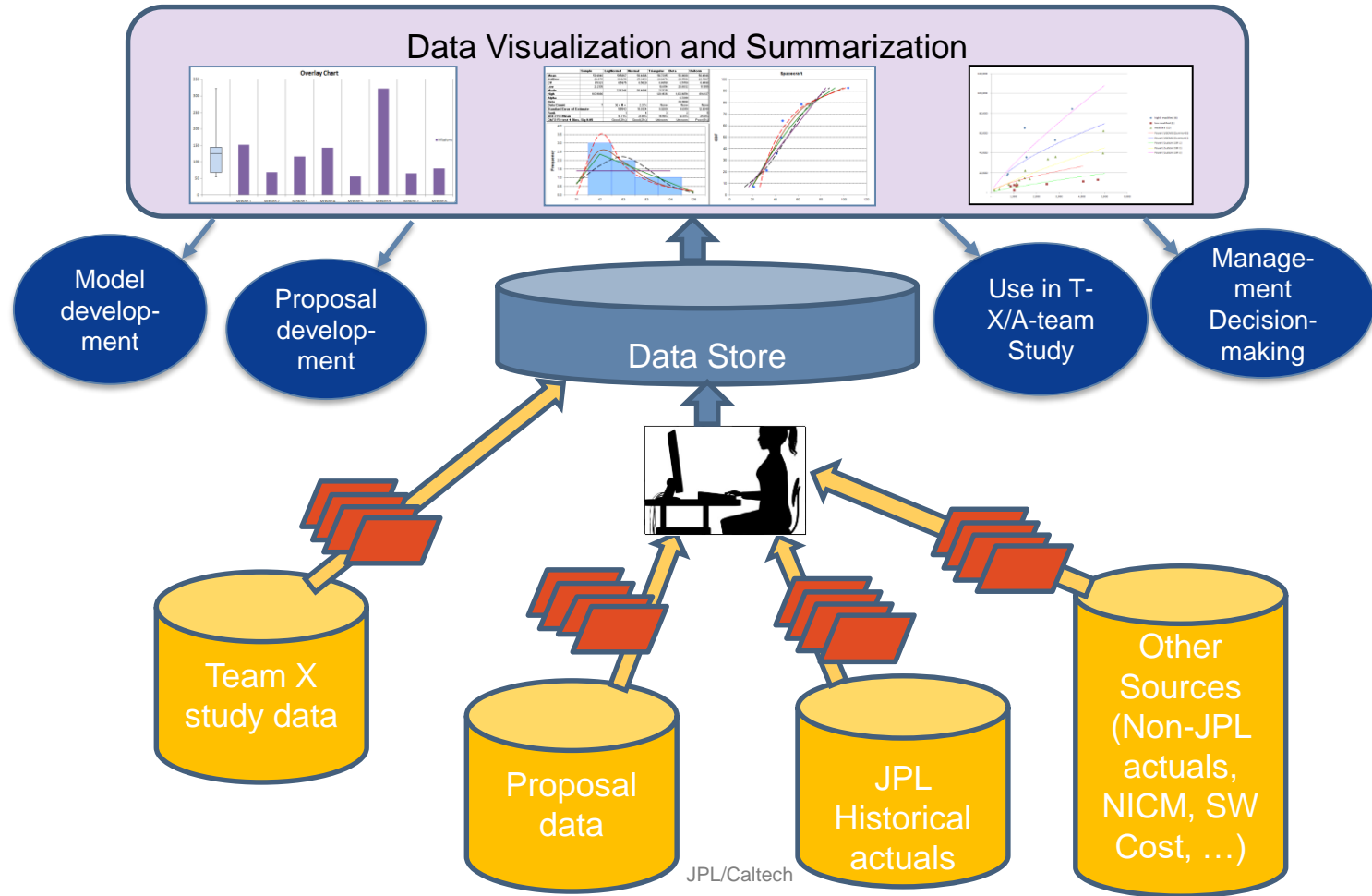
# Mission & Cost Database (MCDB)

## Tasks

- Collect & Normalize Cost and Technical Data
  - Develop operational process to continuously collect and normalize historical mission, proposal, and Team X data for use as reference data
- Mission and Cost Database (MCDB)
  - Establish a database to support model development and real-time estimation and analysis
  - Integrate cost database & methods/tools into design trade space to support A/Xc/X as well as proposal teams
  - Improve customer confidence in formulation cost estimates by enabling real-time review of supporting data
- ICM Upgrades and Migration
  - Integrate ICMs into Foundry MBSE infrastructure to support Team X, external cost estimation and to facilitate improvements to existing capabilities
  - Make tools externally accessible to JPL communities of practice
- Upgraded Cost Capabilities
  - Establish a vetted set of cost estimation and analysis tools
  - Provide a range of CML-appropriate products to customers to enhance decision-maker information
  - Provide continuous review and alignment of current estimates with historical actuals as concepts progress through the formulation lifecycle

# MCDB Architecture

Data Shown is notional



# Mission & Cost Database (MCDB)

## Data Sources

- JPL Historical Mission data from Historical Technical/Cost/Schedule Data Sheets
- Proposal data
- Team X mission study data
- Non-JPL actuals from the One NASA Cost Estimation (ONCE) (database version of the Cost Analysis Data Requirement (CADRe))
- Software costs from the Analogy Software Cost Tool (ASCoT)
- Commercial Bus Catalog – already in Hardware Catalog
- Team Xc cubesat study data
- Historical cubesat data from Cubesat Or Microsat Probabilistic and Analogies Cost Tool (COMPACT) database
- Historical instrument data from the NASA Instrument Cost Model (NICM) database

# Mission & Cost Database (MCDB)

## Data Organization and Storage

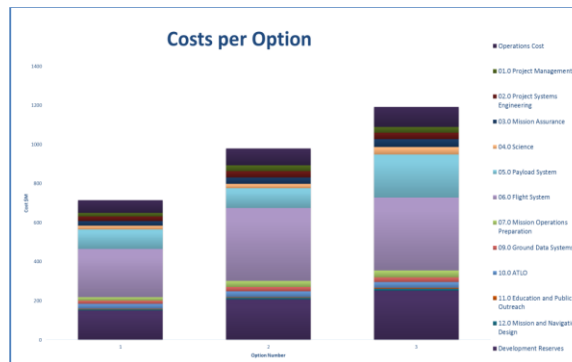
- Provide standard Excel sheet template representation of missions
- Use Excel sheet templates to bulk upload or update cost, technical, and programmatic data
- User interface that allows one to update individual parameters directly
- Allow for reloads/replace if new data is available
- Use scripts to transform Excel sheet data into MCDB database readable formats
- Data Quality assurance tool will be used to ensure data integration correctness

# Mission & Cost Database (MCDB)

## Data Visualization

- Visualize how design, schedule, and programmatic changes propagate through cost with uncertainty at different levels of fidelity by CML

WBS Elements	Option1	Option2	Option3
Project Cost (including Launch Vehicle)	\$990.9 M	\$1254.8 M	\$1235.8 M
Development Cost (Phases A - D)	\$649.8 M	\$894.1 M	\$860.3 M
01.0 Project Management	\$18.8 M	\$30.7 M	\$30.0 M
02.0 Project Systems Engineering	\$23.4 M	\$32.6 M	\$29.8 M
03.0 Mission Assurance	\$23.8 M	\$32.8 M	\$31.5 M
04.0 Science	\$18.5 M	\$22.8 M	\$38.0 M
05.0 Payload System	\$100.0 M	\$100.0 M	\$50.0 M
06.0 Flight System	\$246.9 M	\$373.4 M	\$383.1 M
6.01 Flight System Management	\$4.5 M	\$5.5 M	\$15.1 M
6.02 Flight System Systems Engineering	\$33.8 M	\$43.5 M	\$43.5 M
Element 01	\$200.8 M	\$316.0 M	\$316.0 M
6.04 Power	\$32.7 M	\$35.9 M	\$35.9 M
6.05 C&DH	\$39.1 M	\$60.0 M	\$60.0 M
6.06 Telecom	\$42.0 M	\$50.4 M	\$50.4 M
6.07 Structures (includes Mech. I&T)	\$25.1 M	\$107.1 M	\$107.1 M
6.08 Thermal	\$14.8 M	\$15.1 M	\$15.1 M
6.09 Propulsion	\$9.9 M	\$10.3 M	\$10.3 M
6.10 ACS	\$15.3 M	\$15.3 M	\$15.3 M
6.12 S/C Software	\$21.8 M	\$21.8 M	\$21.8 M
6.14 Spacecraft Testbeds	\$7.8 M	\$8.4 M	\$8.6 M
07.0 Mission Operations Preparation	\$18.3 M	\$31.6 M	\$36.0 M
09.0 Ground Data Systems	\$16.2 M	\$22.7 M	\$23.5 M
10.0 ATLO	\$25.1 M	\$29.4 M	\$28.3 M
11.0 Education and Public Outreach	\$2.4 M	\$3.0 M	\$3.0 M
12.0 Mission and Navigation Design	\$6.4 M	\$8.8 M	\$8.5 M
Development Reserves	\$150.0 M	\$206.3 M	\$198.5 M
Operations Cost (Phases E - F)	\$65.6 M	\$85.3 M	\$100.1 M

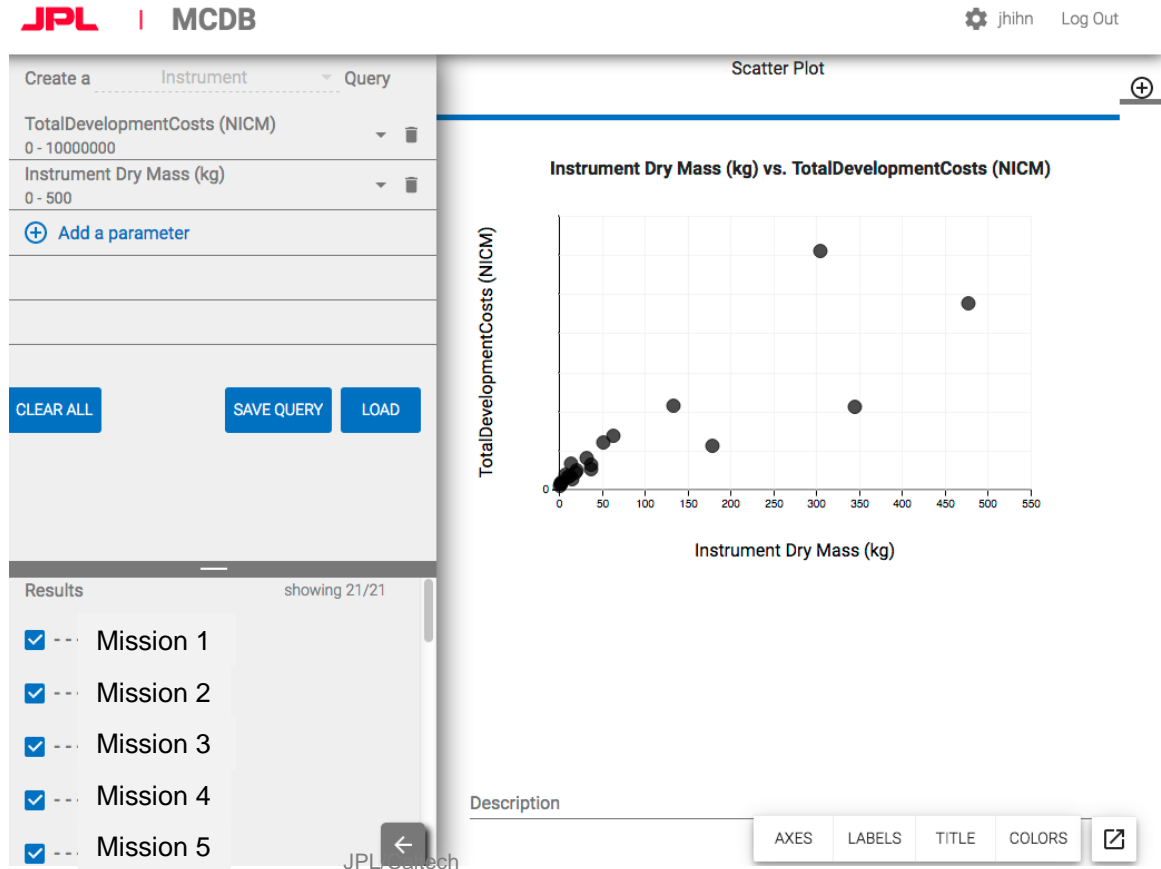


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# Mission & Cost Database (MCDB)

## User Interface

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# “Take-Aways”

- Important to integrate cost into the design process
- Use a diverse suite of cost estimating models for various CMLs
- Establish a single source of cost and technical data
- Use an expanded set of quantitative methods to produce high quality estimates earlier in the design process
- Obtain “buy-in” from all organizations



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